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Blind Identification of Block Interleaved Convolution Code Parameters

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ABSTRACT

Most of the digital communication system uses forward error correction (FEC) in addition with interleaver to achieve reliable communication over a noisy channel. To get useful information from intercepted data, in non-cooperative context, it is necessary to have algoritihms for blind identification of FEC code and interleaver parameters. In this paper, a matrix rank-based algebraic algorithm for the joint and blind identification of block interleaved convolution code parameters for cases, where interleaving length is not necessarily an integer multiple of codeword length is presented. From simulations, it is observed that the code rate and block interleaver length are identified correctly with probability of detection equal to 1 for bit error rate values of less than or equal to 10^{-4}.

Keywords: Convolution code; Block interleaver; Blind identification

1. INTRODUCTION

Shannon[1] has proved that it is possible to achieve probability of bit error arbitrarily close to zero over AWGN channel if channel capacity, $C = B\log_2(1+SNR)$ bits/s, is more than source information rate (R). In digital communications, with the use of well-suited forward error correcting (FEC) code and $R \le C$, it is possible to achieve bit error rate (BER) to any value close to zero over AWGN channel[2]. The convolution code is one type of FEC code that helps in achieving reliable communication over a noisy channel[2-4]. The blind identification of convolution code parameters have been studied based on linear algebraic[5-8], maximum likelihood[9-10], euclidean[11] and soft information and correlation attack[12] algorithms.

Most FEC codes have been designed to correct random errors. The performance of such codes degrades with burst errors, which is defined as, errors occuring in many consecutive bits as compared to random errors occuring in bits independent of each other. To counter the burst channel errors interleaving is commonly used with random error correcting FEC codes. The blind identification of interleaver length based on linear algebriac algorithm has been reported in literatures[13-14].

Blind detection of block interleaved FEC code parameters has been studied[15-17]. Tixier[15], discusses blind identification of block interleaved convolution code, in which interleaver size is identified first using algorithms is presented[13-14] and then algorithm for blind identification of convolution code parameter is presented. Limitation of the algorithms is that it assumes the interleaver length (L) to be an integer multiple of codeword length (n), that is, $L = \lambda n, \lambda > 1, \lambda$ is a positive integer[15-17]. In practice, like, covert operations or surveillance, there may not be such restriction on the interleaver length, that is, $\lambda > 1, \lambda \in \mathbb{R}^+$. In these cases, algorithm presented[15] fails to identify interleaver length. In this paper, an algorithm for blind identification of block interleaved convolution code, where interleaver length is not necessarily an integer multiple of convolution codeword length is presented.

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2. SYSTEM MODEL AND PROBLEM STATEMENT

2.1 System Model

Figure 1 shows the system model assumed for this study, where receiver has a-prior knowledge about symbol rate, carrier frequency, line code, pulse shaping filter and modulation scheme used at transmitter. Further, perfect time and carrier/phase synchronisation are also assumed. With all these assumptions, dashed rectangle portion of the Fig. 1 can be modeled as binary symmetric channel (BSC) with bit error probability p. The system is presented using following Eqn. (1).

$$y[l] = x[l] \oplus w[l], (1 \le l \le N) \quad (1)$$

where $w[l] = 1$ with probability p, $\oplus$ represents modulo-2 addition and N is number of transmitted bits.

2.2 Problem Statement

Given an N bit sequence y, identify the convolution code rate k/n and interleaver length L, where n and L need not be integer mutiple of each other, that is, $L = \lambda n$, $\lambda > 1$ and $\lambda \in \mathbb{R}^+$.

3. BLIND IDENTIFICATION OF CONVOLUTION CODE PARAMETERS

Ahmed[5], presents an algorithm for blind identification of convolution code parameters for a noiseless channel. Assuming the detected N bit sequence, $\mathrm{y} = [b_1 b_2 \ldots b_N]$, as an input to the identification algorithm, the flow chart for the identification process is shown in Fig. 2. The ratio of difference between R_a's

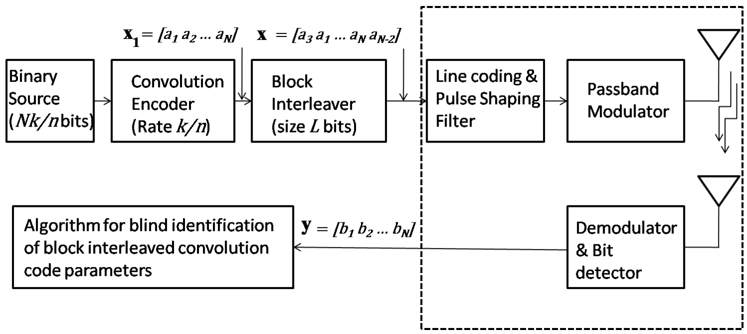

Figure 1. The system block diagram.

to difference between N_a's is identified as k/n. For identification of parameters from a sequence y affected with noise, an iterative algorithm is presented in paper[8]. In each iteration, the rows of the matrix M (as described in Fig. 2) are permuted. This permutation process increases the probability of obtaining the non-erroneous pivots during the Gauss elimination method. This iterative algorithm is able to detect the presence of the convolution code for the bit error rate value of less than or equal to 10^{-2} with probability of detection equal to 1.

For the rate k/n convolution code, number of columns (C) and rank (R) of first rank-deficient matrix are given by Eqns. (2) and (3)[5], respectively, where μ' is memory of the dual code. For the algorithm presented in Fig. 2, values of N_a and R_a of first rank deficient matrix are equal to C and R, respectively.

$$C = n\left\lfloor \left(\mu' \big/ n-k\right) \right\rfloor + 1 \tag{2}$$

$$R = C(k/n) + \mu' \tag{3}$$

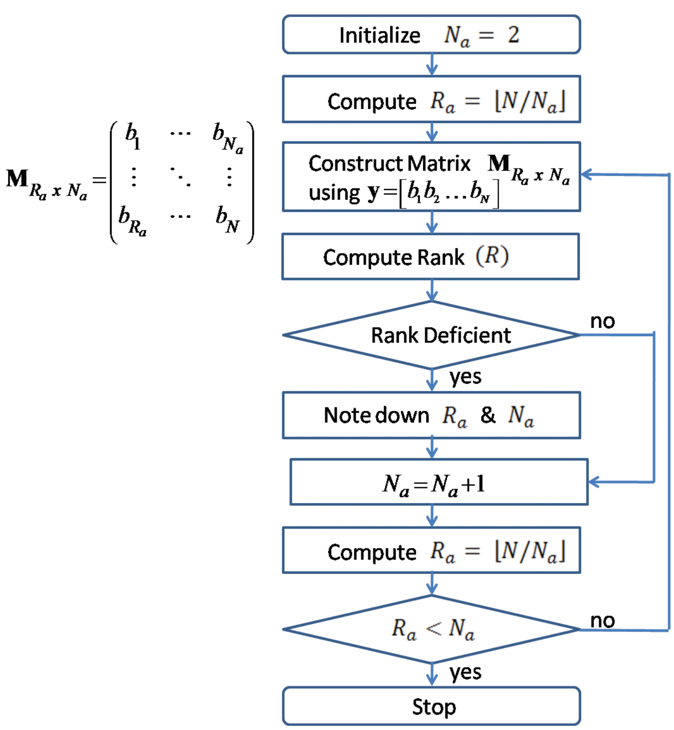

Figure 2. Flow chart for blind identification of convolution code parameters for a noiseless transmission[7].

Equation (2) can be interpreted as criterion C1,

C1: Since the value of $\left\lfloor \left(\mu' \big/ n-k\right) \right\rfloor + 1$ is a positive integer, for convolution codes, the minimum number of columns C, of first rank-deficient matrix, is an integer multiple of codeword length n. The value of $\left\lfloor \left(\mu' \big/ n-k\right) \right\rfloor + 1$ conveys the number of codewords, that is, C/n.

4. BLIND IDENTIFICATION OF BLOCK INTERLEAVER PARAMETER

The blind identification of interleaver parameters has been studied using linear algebraic approach[13-14], which discusses an algorithm for identification of block interleaver length ($L = \lambda n, \lambda > 1, \lambda$ is a positvie integer). The basic idea in this algorithm is same as the algorithm of blind identification of convolution code parameters. We get an integer number of codewords in a block of L bits, therefore, the number of columns of first rank-deficient matrix is L. In this case the difference between N_a's of the two consecutive rank-deficient matrices is the identified interleaver length.

5. PROPOSED ALGORITHM FOR BLIND IDENTIFICATION OF BLOCK INTERLEAVED CONVOLUTION CODE PARAMETERS

Ahmed[5], *et al.* discusses the case of identification of FEC code parameters for non noisy environment. The performance of iterative algorithm presented[8] for a noisy channel depends upon the threshold value chosen for the detection of the dependent columns of the matrix M. The threshold value is determined from the knowledge of channel variance. One limitation of the algorithm presented in papers[13-14] is that it assumes the interleaver length to be an integer multiple of codeword length. A new algorithm for blind identification of block interleaved convolution code parameters, in case of noisy channel, has been proposed. The algorithm addresses the limitations of the algorithms presented in papers[5, 8, 13, 14].

5.1 Proposed algorithm

As interleaving length is not integer multiple of codeword length, we get an integer number of codewords in $D = L.C.M\,(n, L)$ bits. The flow chart for identification of D and k/n is given in Fig. 3. The difference between N_a's of the two consecutive rank-deficient matrices is identification of D and ratio (A/D) is identified value of k/n. In flowchart, condition $A/D \geq 1$ ensures that rank-deficient matrices are registered for identification of D and k/n only when rows of the matrix M contain integer multiple codewords, therefore, it ensures that rank-deficient matrix due to noise are eliminated for the identification process. The proposed algorithm, therefore, does not require channel knowledge.

In proposed algorithm, we get an integer number of codewords in D bits. The number of columns of the first rank-deficient matrix in this scheme is given by the following two cases.

Case 1: $D \geq C$

The first D bits contain integer number of codewords and the number of columns of first rank-deficient matrix is equal to D as it satisfies criterion C1.

Case 2: $D < C$

The number of columns in first rank-deficient matrix cannot be equal to D as it violates criterion C1. As D bits contain integer number of codewords, hence, the number of columns of first rank-deficient matrix has to be integer multiple of D, that is, equal to αD (α is a positive integer, such that, $\alpha D \geq C$ and $\alpha = \left\lceil C/D \right\rceil$). (Since $\alpha D \geq C$ implies $\alpha D / n \geq C / n$, hence C1 is satisfied).

The above two cases can be summarised as criterion C2.

C2: The minimum number of columns of first rank deficient matrix of block interleaved convolution code is αD ($\alpha = \left\lceil C/D \right\rceil$, α is a positive integer) such that, it satisfies criterion C1.

The algorithms presented in papers[5, 8, 13, 14] and our algorithm identify n and when interleaving is not integer multiple of codeword length. For identified and n, there exist multiple solutions for L In this paper, case is addressed, where, only two solutions for L exist, namely, L_1 and L_2 ($L_2 = L = D$).

5.2 Method to Choose between L_1 and L_2

Remove L_1 bits from the beginning of N received bits.

Case A: L_1 used at transmitter

By removing L_1 bits, we exhaust $\left\lceil L_1/n \right\rceil$ codewords from the received N bits. Therefore, there exists $\beta = (\alpha D/n) - \left\lceil L_1/n \right\rceil$ codewords in the first $\alpha D - L_1$ bits. Concatenation of subsequent L_1 bits to $\alpha D - L_1$ bits adds $\left\lceil L_1/n \right\rceil$ codewords to β, therefore, there are in total $\beta + \left\lfloor L_1/n \right\rfloor$ codewords in αD bits. We have to check whether $\beta + \left\lfloor L_1/n \right\rfloor \geq \frac{C}{n}$ such that criterion C2 is satisfied.

Let us consider three possibilities:

(a) In case of $D > C$, α is equal to 1. As n is an integer multiple of D and C and $n \neq 1$, D is greater than $C+1$.

Therefore, $\beta + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{D}{n} - \left\lceil \frac{L_1}{n} \right\rceil + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{D}{n} - 1 \geq \frac{C}{n}$

(b) In case of $D < C$, α is equal to $\left\lceil C/D \right\rceil$. The value of α is, therefore, greater than 1 and it is positive integer and $\alpha D \geq C$.

If $\alpha D > C$, as αD and C both are integer multiple of n, $n \neq 1$ so $\alpha D > C+1$. Hence,

$$\beta + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{\alpha D}{n} - \left\lceil \frac{L_1}{n} \right\rceil + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{\alpha D}{n} - 1 \geq \frac{C}{n}.$$

Therefore, both cases (a) and (b) (when $\alpha D > C$) ensure that $\beta + \left\lfloor \frac{L_1}{n} \right\rfloor \geq \frac{C}{n}$. The number of columns of first rank-deficient matrix, hence, turns out to be equal to αD, which is same as computed for N bits.

If $\alpha D = C$ then $\beta + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{\alpha D}{n} - \left\lceil \frac{L_1}{n} \right\rceil + \left\lfloor \frac{L_1}{n} \right\rfloor = \frac{C}{n} - 1 < \frac{C}{n}$. Therefore, we have to concatenate subsequent m (m is a positive integer) blocks of L_1 bits to αD bits such that it satisfies $\beta + \left\lfloor \frac{L_1}{n} \right\rfloor \geq \frac{C}{n}$. Thus, in case of $\alpha D = C$, the number of columns of first rank-deficient matrix is $\alpha D + mL_1$.

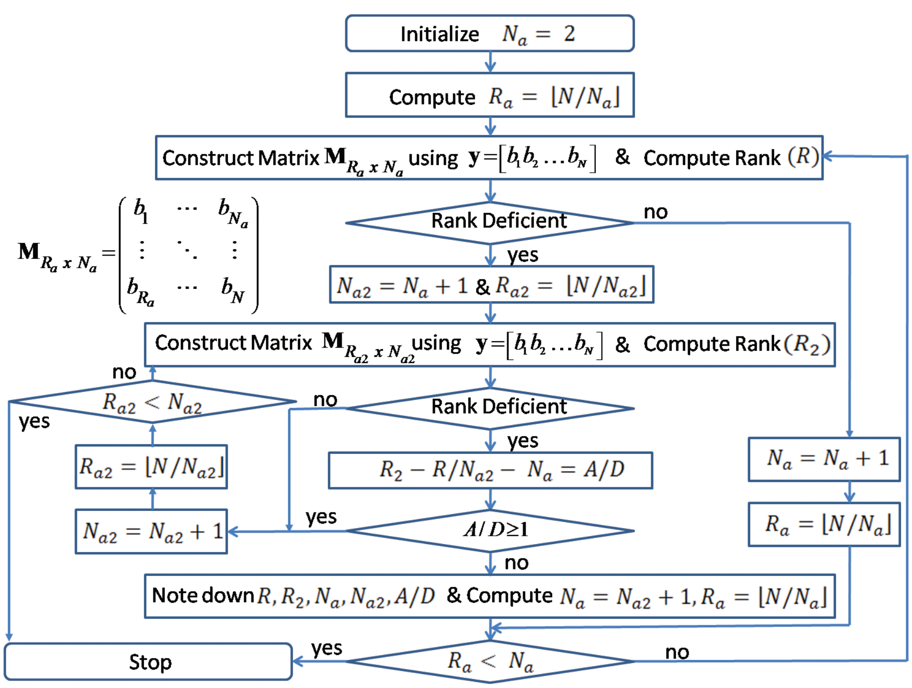

Figure 3. Flow chart for blind identification of block interleaved convolution code.

(c) In case of $D = C(\alpha = 1)$. Hence, $\beta + \left\lfloor L_1/n \right\rfloor = \frac{D}{n} - \left\lceil L_1/n \right\rceil + \left\lfloor L_1/n \right\rfloor = \frac{D}{n} - 1 < \frac{C}{n}$. Therefore, we have to concatenate subsequent m (m is a positive integer) blocks of L_1 bits to αD bits such that it satisfies $\beta + \left\lfloor L_1/n \right\rfloor \geq \frac{C}{n}$. Thus, in case of $D = C$, the number of columns of first rank-deficient matrix is $\alpha D + mL_1$.

Case B: L_2 used at transmitter

Removal of L_1 bits from the beginning of N received bits, results in three possibilities, namely,

(a) We exhaust maximum codewords, that is, L_1 from first αD bits

In case of L_1 codewords removed, there exists $\beta = \left(\alpha D/n\right) - L_1$ codewords in the first $\alpha D - L_1$ bits. Concatenation of subsequent L_1 bits to $\alpha D - L_1$ bits adds 0 codewords to β. Therefore, in the case of L_2 used at transmitter, the number of columns of first rank-deficient matrix is not equal to αD. Instead of concatenating subsequent L_1 bits if we concatenate L_2 bits to $\alpha D - L_1$ bits, L_1 codewords are added to β codewords. Therefore, there are totally $\left(\alpha D/n\right)$ codewords in $\alpha D - L_1 + L_2$ bits, which are $\geq (C/n)$. At this point, $\alpha D - L_1 + L_2$ is not integer multiple of n, as L_1 is not multiple of n. Concatenating subsequent L_1 bits to $\alpha D - L_1 + L_2$ bits makes total number of columns of the matrix equals to $\alpha D + L_2$. This will satisfy the criterion C2 as $L_2 = D$.

(b) We exhaust minimum codewords, that is, $\gamma = \left\lceil L_1/n \right\rceil$ from first αD bits

In case of $\left\lceil L_1/n \right\rceil$ codewords removed, there exists $\beta = (\alpha D/n) - \left\lceil L_1/n \right\rceil$ codewords in the first $\alpha D - L_1$ bits. This situation arises when first L_1 bits are interleaved across first L_1 bits. Thus, concatenating subsequent L_1 bits to $\alpha D - L_1$ bits adds $\left\lfloor L_1/n \right\rfloor$ codewords to existing β codeords. Further analysis is same as Case A and its sub-cases.

(c) We exhaust number of codewords such that, $\gamma <$ exhausted codewords $< L_1$

Let the number of exhausted codewords is equal to $\gamma + 1$, that is, $\left\lceil L_1/n \right\rceil + 1$ codewords. There exists $\beta = (\alpha D/n) - \left\lceil L_1/n \right\rceil - 1$ codewords in the first $\alpha D - L_1$ bits. Thus, concatenating subsequent L_1 bits to $\alpha D - L_1$ bits, adds $\left\lfloor L_1/n \right\rfloor - 1$ codewords to existing β codeords. That is, total number of codewords in αD bits is equal to $\left(\frac{\alpha D}{n}\right) - \left\lceil L_1/n \right\rceil - 1 + \left\lfloor L_1/n \right\rfloor - 1 = \left(\frac{\alpha D}{n}\right) - 3 \leq \left(\frac{\alpha D}{n}\right)$. This condition does not satisfy the criterion C2. The minimum number of columns required, therefore, is more than αD columns.

As, the number of columns required for first rank-deficient matrix is more than αD columns for $\gamma + 1$ removed codewords, removing codewords more than $\gamma + 1$ or $\leq L_1$, will not satisfy the criterion C2. Therefore, for sub-cases a and c, instead of concatenating L_1 bits, we have to concatenate $\geq L_1 + L_2$ bits so that criterion C2 is satisfied. The number of columns required for first rank-deficient matrix will always be more than αD for sub-cases a and c.

The above two cases **A** and **B** can be summarised as Table 1.

5.3 Limitations of Proposed Method

This method fails to differentiate between L_1 and L_2 in the following situations.

i. In case of exhausted codewords are equal to $\left\lceil L_1/n \right\rceil$.

ii. If a rank $R_{D2} = C_2(k/n) + \mu', (C_2 = \alpha D + D)$, of the second rank-deficient matrix, computed for received N bits, is such that, $R_{D2} < \alpha D$.

In case of limitation 1, it is observed from simulations that with L_1 used at the transmitter and $N - L_1$ bits, rank of the first rank deficient matrix, with the number of columns equals to $C_1 = \alpha D + mL_1$, increases by ≤ 2 compared to the rank of the matrix (computed for N bits) with equal number of columns C_1 by concatenating subsequent L_1 bits to $N - L_1$ bits. Whereas, for L_2 used at the transmitter rank increment is more than 2. The reason is that in case of L_2 used at transmitter, removing first L_1 bits from αD bits at receiver,

Table 1. Summary of method to choose between L_1 and L_2

A. L_1 used at transmitter	**Three possibilities**	**Sub-cases**	**Number of columns of first rank-deficient matrix**	**Remarks**
(Exhausted Codewords (τ) from first αD bits = $\left\lceil L_1/n \right\rceil$)	$D > C$	---------	αD	Removing first L_1 bits from received N bits then concatenating subsequent L_1 bits to first αD-L_1 bits
	$D < C$	$\alpha D > C$	αD	
		$\alpha D = C$	$\alpha D+mL_1$	
	$D = C$	----------	$\alpha D+mL_1$	
B. L_2 used at transmitter	**Exhausted Codewords (τ) from first αD bits**			
$\alpha D+L_2$	L_1 or $\gamma < \tau < L_1$		$\geq \alpha D+L_2$	Removing first L_1 bits from received N bits then concatenating subsequent $\geq L_1+L_2$ bits to first αD-L_1 bits
	$\gamma = \left\lceil L_1/n \right\rceil$		Same as L_1 used at transmitter	

most of the times, deletes more codewords than for the case of L_1 bits used at transmitter from the first αD bits. Therefore, more independent bits are left in first $\alpha D - L_1$ bits in case of L_2 bits used at transmitter than for the case of L_1 bits used at the transmitter. For limitation 2, in case of L_2 used at the transmitter, rank of the matrix with the number of columns equals to $\alpha D - L_1 + L_1 = \alpha D$ (Removing first L_1 bits from the N bits then concatenating subsequent L_1 bits to first $\alpha D - L_1$ bits) would be less than αD as $R_{D2} < \alpha D$ and $\alpha D < \alpha D + D$. Therefore, for both cases, L_1 and L_2 used at transmitter, the number of columns of first rank-deficient matrix is αD. From simulations it is observed that for L_1 used at the transmitter and $N - L_1$ bits, rank of the first rank deficient matrix, increases by 1 or 2 compared to the rank of the matrix computed for N bits. Whereas, for L_2 used at the transmitter rank increment is more than 2. The reason behind this is same as given for limitation 1.

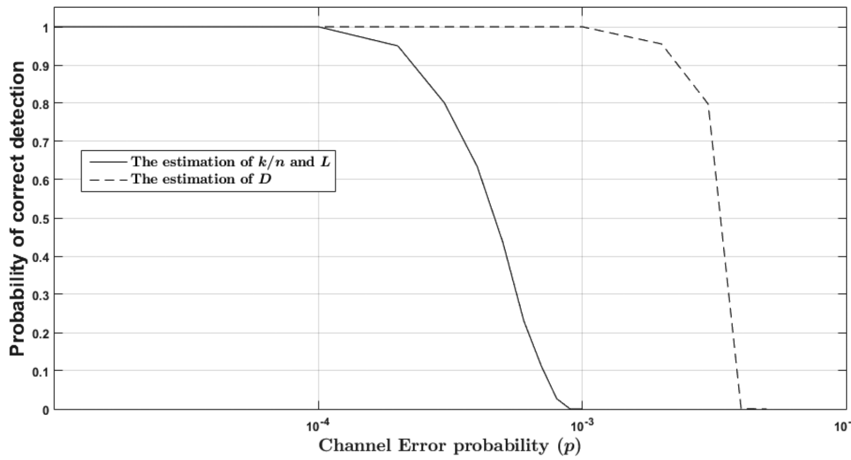

Figure 5. The probability of correct detection vs BER for BSC for identification of block interleaved convolution code parameters.

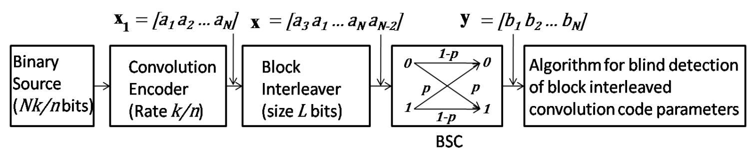

Figure 4. The block diagram of simulation setup.

6. SIMULATION SETUP AND RESULTS

The simulation has been performed in MatLab to evaluate performance of proposed algorithm. In simulation, the sequence consisting i.i.d random variables, chosen from discrete uniform distribution is generated. The length of the random sequence is such that after convolution encoding of random sequence, the total number of encoded bits is, $N \approx 50,000$. The encoded sequence is divided into blocks of the length L bits and each block is then block interleaved. The convolutional coded block interleaved sequence is then transmitted over a BSC, having bit error probability p. The output of the BSC is used as an input to proposed algorithm for the identification of k/n and L. The Fig. 4 shows the block diagram of simulation setup. The performance of an algorithm for convolution codes $(2,1,7),(3,1,3),(3,1,6),(3,2,5),(4,3,4),(4,1,7),(4,1,10)$ and $(5,1,3)$ $L = 5,6,7,8,9,10,12,14,15,18,21,28$ and 30 has been simulated. In simulation, it is observed that performance of proposed algorithm is same in terms of probability of correct detection for different code rates and interleaver lengths. The Fig. 5 shows the simulation results.

From Fig. 5, it is observed that D is identified correctly with probability of detection equal to 1 for the BER values of less than or equal to 10^{-3}. The coderate k/n and L are identified correctly with probability of detection equal to 1 for the BER values of less than or equal to 10^{-4}.

7. CONCLUSIONS

The algorithm for joint identification of interleaver length and convolution code parameters where L need not to be integer multiple of n has been discussed. In this case $L = \lambda n, \lambda > 1, \lambda \in \mathbb{Z}^{+}$, proposed algorithm and algorithm presented in[15] identifies $D = LCM(n, L)$. In this paper, an algorithm is presented that identifies L using detected values of D and n. As proposed algorithm is non-iterative, therefore, computational complexity of algorithm is less than iterative algorithms presented[8,13]. The performance of algorithms presented in[8,13], depends on the channel variance knowledge. In proposed algorithm channel information is not required. The proposed algorithm identifies D correctly with probability of detection equal to 1 for the BER values of less than or equal to 10^{-3}. The coderate k/n and L are identified correctly with probability of detection equal to 1 for the BER values of less than or equal to 10^{-4}. In general, all FEC schemes provide coding gain for BER upto 10^{-2} to 10^{-1} depending upon the type of modulation and communication channel under consideration. Algorithm developed, to identify interleaver length from detected n and D in this paper can be used with the algorithms presented in[8,13] for identification of block interleaver length even at high BER of the order of 10^{-2}. In this paper, algorithm is proposed for hard decision decoding. The development of algorithm for soft decision decoding may be consider as future work.

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This research work was conceptualised and later on literature survey, mathematical analysis, simulations, data interpretation and prepared manuscript by him.